THE EFFECTS OF IRRIGATING SOILS OF THE PROPOSED SHADEHILL PROJECT WITH WATERS HIGH IN SODIUM AND BICARBONATE IONS [1]

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INTRODUCTION

Throughout the history of irrigation agriculture, problems have frequently arisen with respect to the decline of crop production after many, or in some instances, only a few years' irrigation. All irrigation waters contain salts in varying proportions and concentrations. Adequate drainage is necessary to prevent the accumulation of those salts which are harmful.

Reeve[1] discussed this need from two separate standpoints: (a) unfavorable conditions for crop growth which may occur as a result of adverse soil conditions, which are in turn caused by the exposure of the soil to certain salts; and (b) the influence upon or inhibition of crop growth due to the accumulation in the soil of excessive salts. This paper is primarily concerned with the first category.

Byers[2] (pp. 976-977) *et al.* discussed at some length the soil changes taking place when sodium becomes the principal absorbed cation. They stated in part that

> "If the Ca content is low and the Na content high, the Na-clays will hydrolyze to form free NaOH as soon as the greater part of the salts has been removed. This results in the deflocculation of the colloidal particles, and the soil becomes sticky, jelly-like, and impenetrable to water . . . The soil solution becomes very strongly alkaline, and very few plants can survive under these conditions."

Magistad and Christensen[3] stated that improvement of soil productivity does not depend solely on the removal of soluble salts; in the case of soils containing appreciable quantities of absorbed Na, it is necessary to substitute Ca for Na. Three sources of Ca were discussed, namely, (a) the irrigation water itself; (b) soil amendments containing Ca, such as gypsum; and (c) Ca-containing compounds of the soil, such as gypsum or $CaCO_3$. If (b) or (c) were to be used, the problem would remain of getting the Ca into solution.

Eaton (4) in 1950 noted that in studies of the Tigris-Euphrates and Nile valleys, some of the oldest irrigated regions of the world, it appeared that the CO_3 and HCO_3 ions in the water increased the accumulation of Na beyond the levels expected on the basis of the SSP (soluble sodium percentage). He believed that an amount of Ca plus Mg ions normally making up a very favorable percentage of all cations could be reduced or even eliminated under adverse conditions, if sufficient CO_3 and HCO_3 ions were present to cause precipitation of some or all of the Ca and Mg ions. If such a reaction did, in fact, occur, the SSP would be greatly increased. He pointed out that this precipitation reaction would take place when the soil solution had already undergone considerable reduction in volume, and considered it unlikely that such a reaction would go to completion. He proposed a measure of water quality which he termed "residual Na_2CO_3" calculated (in meq./1) as the sum of the CO_3 and HCO_3 ions minus the sum of the Ca plus Mg ions, where this difference would be positive. He also suggested calculating "possible sodium percentage," calculated as Na x 100% [Na + (Mg + Ca) − (HCO_3 + CO_3)]. The possible Na percentage, of course, could never exceed 100. He felt that this measure would give a better prediction of ESP (exchangeable sodium percentage) in some cases than the normally used SSP figure.

The staff of the U. S. Salinity Laboratory (5) in 1954 suggested a method of predicting soil ESP based on a calculated ratio which they termed "sodium adsorption ratio" or SAR. They found a very good correlation between ESP and SAR values. The SAR is calculated as $Na \left\{\frac{Ca + Mg}{2}\right\}^{0.5}$, all concentrations being expressed as meq./1, as they will be throughout this paper. Obviously, if the ionic concentration quadrupled (that is, if the soil solution shrank to one-fourth its original volume), the SAR would be doubled. Also, if some of the Ca and Mg ions were precipitated from the soil solution the SAR would be further increased.

Wilcox (6) *et al.* conducted pot culture studies over a period of approximately 3 years and concluded that where no rainfall is involved, waters containing over 2.5 meq./1 of "residual Na_2CO_3" are probably not safe; those containing from 1.25 to 2.5 meq./1 are marginal; and those containing less than 1.25 meq./1 are probably

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safe. They found that the degree of leaching will modify these results to some extent.

EXPERIMENTAL PROCEDURE

Studies were initiated prior to the 1953 growing season at the Shadehill Development Farm, which is situated on a high terrace (approximately 100 feet above the surface of the Grand River), and immediately adjacent to the Shadehill Dam. This site was believed to be typical of the gently sloping terrace lands proposed for irrigation. Results of mechanical analyses indicate that, in general, the surface soils and subsoils are of clay loam or sandy loam texture. Understrata are predominantly sandy loams, grading into open sands or gravel at depths of 42 to 60 inches. Chemical determinations revealed very low exchangeable sodium and gypsum content in all samples taken.

Objectives of the original experimental design were stated as follows:

(a) To determine the effect of the application of low-quality water from Shadehill Reservoir upon the accumulation of salts and alkali in the soils of the Shadehill Unit and upon crop production.

(b) To determine the effect of leaching and chemical amendments upon the movement of water into and through the root zone, and upon the removal of exchangeable sodium and soluble salts.

(c) To compare irrigated and dryland crop production.

To implement these objectives a design was developed incorporating seven different treatments, applied to randomly selected plots in five replications. Plots measured 100 x 120 feet. Planned treatments were as follows:

1. No irrigation (check).
2. Optimum irrigation (as necessary for good crop production).
3. Optimum irrigation plus periodic leaching.
4. Optimum irrigation plus the addition of gypsum in amounts chemically equivalent to the "residual Na_2CO_3."
5. Optimum irrigation plus addition of gypsum plus periodic leaching.
6. Frequent irrigation to maintain soil moisture near field capacity.
7. Frequent irrigation plus periodic leaching.

The leaching practice prescribed for each of the odd-numbered irrigation treatments was postponed until such time as salt accumulation made it necessary; thus far, it has not been necessary. The plots were planted to alfalfa in the summer of 1952 and have remained in this crop ever since. This was considered a good choice because alfalfa transpires water throughout most of the frost-free season. Over the 6-year period, treatments 2, 3, 4, and 5 have received a total of about 163 inches of irrigation water and treatments 6 and 7 have received approximately 180 inches.

The water used for irrigating was sampled frequently for analysis. Table I summarizes these analyses. The present water quality is believed to be near the long-term expected quality for the reservoir.

TABLE I

A SUMMARY OF ANALYSES OF SHADEHILL RESERVOIR WATERS FOR THE YEARS 1953 TO 1958

Date	Cond. $ECx10^6$	pH	TDS (ppm)	Na% Found	Na% Possible	Residual Na_2CO_3 (me./liter)	SAR
8/13/53	830	8.0	566	65.9	95.5	1.28	4.86
6/30/54	1200	8.4	684	73.9	100	2.19	7.04
5/10/55	1280	8.5	922	74.1	98.3	3.00	7.69
8/27/56	1380	8.3	882	75.6	98.6	3.10	8.36
8/16/57	1400	8.3	908	79.8	98.3	3.65	9.85
10/ 3/58	1500	8.4	960	79.8	98.1	4.34	10.53

METHODS

Chemical determinations were performed, with a few exceptions, by the Soil Testing Laboratory of the U. S. Bureau of Reclamation at Huron, South Dakota. Some water analyses were performed by the Soil Testing Laboratory at South Dakota State College. Both laboratories use the procedures recommended by the staff of the U. S. Salinity Laboratory (see reference 5).

RESULTS

Exchangeable sodium content is summarized in Table II for the 6 years' work, as well as the initial (1952) sampling.

Cation exchange capacity of these soils ranges from about 20 to about 24 me./100 grams of soil.

The computed apparent equilibrium between soil ESP and the water is reached at levels of about 8 to 9% under treatments 2 and 6 and at levels of less than 7.5% under treatment 4, where gypsum is used as a water amendment in amounts chemically equivalent to the "residual Na_2CO_3."

TABLE II

ANNUAL SUMMARY OF EXCHANGEABLE SODIUM (me./100g.) BY INCREMENTS OF DEPTH

Treatment	Depth (inches)	1952	1953	1954	1955	1956	1957	1958
2	0-6"	0.16	0.63	1.59	1.77	1.70	1.60	1.79
	6-12"	0.19	0.45	1.27	1.95	1.97	2.06	2.23
	12-18"	0.20	0.26	0.87	1.49	1.69	1.65	1.92
4	0-6"	0.15	0.75	1.37	1.30	1.40	1.12	1.29
	6-12"	0.15	0.48	1.19	1.59	1.72	1.55	1.67
	12-18"	0.17	0.32	0.76	1.20	1.49	1.36	1.62
6	0-6"	0.19	0.63	1.51	1.85	1.90	1.71	1.86
	6-12"	0.20	0.40	1.20	1.85	2.16	1.93	2.22
	12-18"	0.27	0.26	0.88	1.37	1.72	1.71	1.83

Infiltration studies were performed each year by means of double-ring infiltrometers as a measure of soil permeability. A decrease in permeability would accompany the deterioration of soil structure. Both would result from the dispersion of soil colloids by excessive quantities of exchangeable Na. Results of these studies are summarized in Table III.

There appears to be little, if any, difference in final slope of the intake curves for treatments 2 and 6. Treatment 4 is possibly slightly more permeable than 2 or 6, but the difference is again very small, and in proportion to the magnitude of depth change involved, is probably inconsequental. Intake rates for 1955 were considerably lower than those obtained in 1954, and at the time aroused concern. However, in 1956 intake rates were higher than those of 1954, and they have continued to improve since then.

The progressions of exchangeable sodium and of the water intake characteristics in the period 1952-1958 are plotted in Figure 1. These graphs give a graphic depiction of these characteristics in the period of irrigation of treatments 2, 3, 6, and 7, and the 0-12" depth of plot 4. The field infiltration rates indicate a considerably greater water intake rate than the "disturbed sample" tests. This disparity has been quite consistent and would merit further study.

Yield samples were taken prior to the removal of each cutting of alfalfa. These have shown that it is readily possible to harvest

TABLE III

A SUMMARY OF FIELD INFILTRATION STUDIES

Treatment	Year	Inches of Infiltration at Time 15 min.	30 min.	60 min.	120 min.
2	1954	0.50	0.70	1.08	1.64
	1955	0.32	0.48	0.70	1.08
	1956	0.62	0.96	1.43	2.28
	1957	0.84	1.31	2.02	3.14
	1958	0.71	1.10	1.76	2.87
4	1954	0.54	0.80	1.20	1.80
	1955	0.38	0.54	0.80	1.22
	1956	0.67	1.00	1.48	2.47
	1957	0.65	1.09	1.83	3.58
	1958	0.73	1.24	2.05	3.33
6	1954	0.62	1.01	1.53	2.50
	1955	0.48	0.70	1.07	1.52
	1956	0.71	1.02	1.61	2.21
	1957	0.42	0.72	1.13	1.85
	1958	0.82	1.20	1.88	2.99

up to 6 tons of alfalfa hay per acre per year, taken as 3 cuttings, under irrigation. Dry-land production over the 6-year period has averaged approximately 1 ton per acre per year. In this period of 6 years there were 2 years during which no alfalfa was harvested from the dry-land plots.

DISCUSSION AND CONCLUSIONS

The effect of the application of low-quality water from Shadehill Reservoir upon the accumulation of salts and alkali in soils typical of the proposed Shadehill Irrigation Unit was studied. It appears that exchangeable sodium percentages are in equilibrium with the water being applied (at least in the upper portions of the soil profile) and that these equilibria are reached at levels somewhat lower than those predicted by the SAR-ESP nomograph (5, p. 73). Under the conditions of annual rainfall found at this location (about 15 inches per year), the "residual Na_2CO_3" content of the water has not, under field conditions, induced further increases in exchangeable Na beyond those levels otherwise anticipated.

The effects of leaching were not studied in the field because this did not become necessary. Gypsum was applied with the irrigation water in amounts chemically equivalent to the "residual

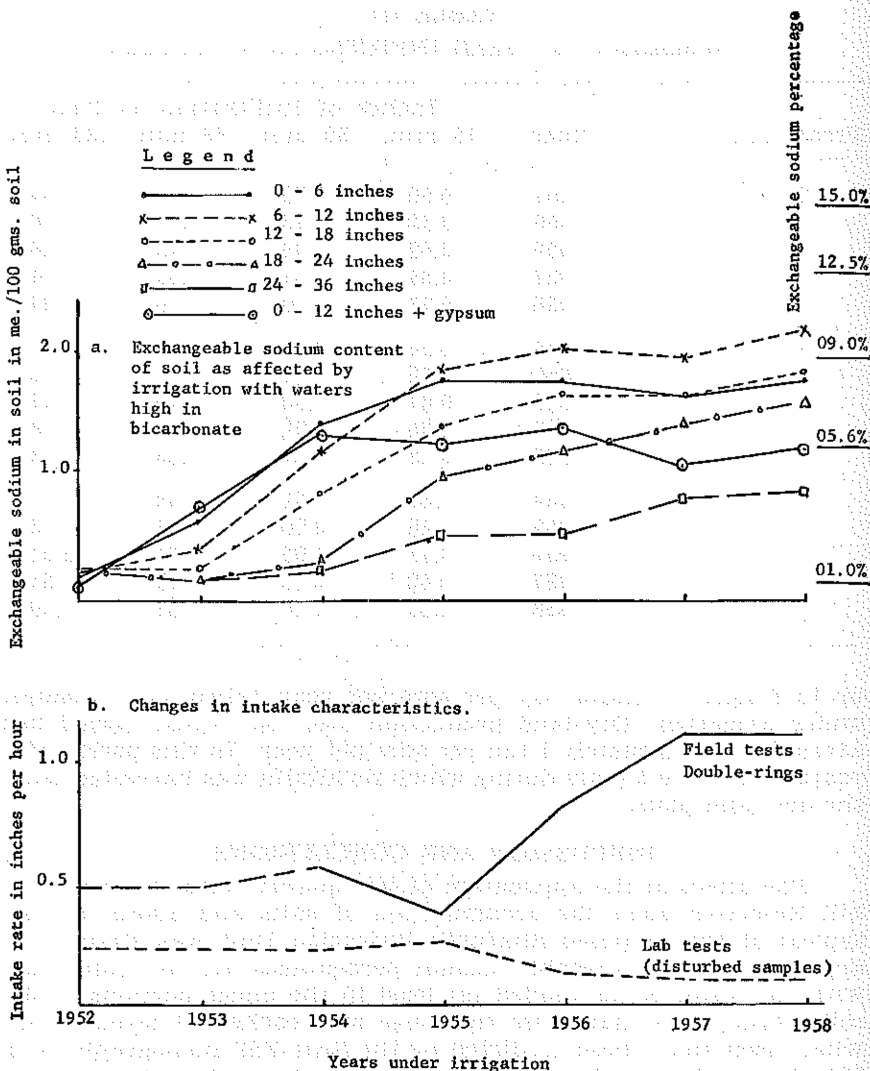

Figure 1. Progression of Exchangeable Sodium and Water Intake Characteristics in Soil of the Shadehill Experimental Farm, South Dakota

Na_2CO_3" and appeared to induce equilibrium between ESP and sodium in the water at levels somewhat lower than were otherwise found. Infiltration rates were equal or possibly slightly superior under the gypsum treatment.

Alfalfa production under irrigation was found to be comparable to that in other areas of the state under irrigation. This was equal to about a five-fold increase over dry-land production on these same soils.

LITERATURE CITED

1. Reeve, Ronald C., The Relation of Salinity to Irrigation and Drainage Requirements. Internat'l Comm. Irrig. and Drainage Proc. Third Cong. 10:175-187 (1957) illus.
2. Byers, H. G., *et al.* Formation of Soil. U. S. Dept. Agr. Yearbook, 1938:948-978.
3. Magistad, O. C., and Christiansen, J. E. Saline Soils—Their Nature and Management. U. S. Dept. Agr. Circ. No. 707, pp. 32 (1944) illus.
4. Eaton, Frank M., Significance of Carbonate in Irrigation Waters. Soil Sci., 69:123-133. 1950.
5. U. S. Salinity Laboratory Staff, Richards, L. A., Ed. Diagnosis and Improvement of Saline and Alkali Soils. U. S. Dept. Agr. Agriculture Handb. No. 60:160 pp. (1954) illus.
6. Wilcox, L. V., *et al.* Effect of Bicarbonate on the Suitability of Water for Irrigation. Soil Sci. 77:259-266 (1954).